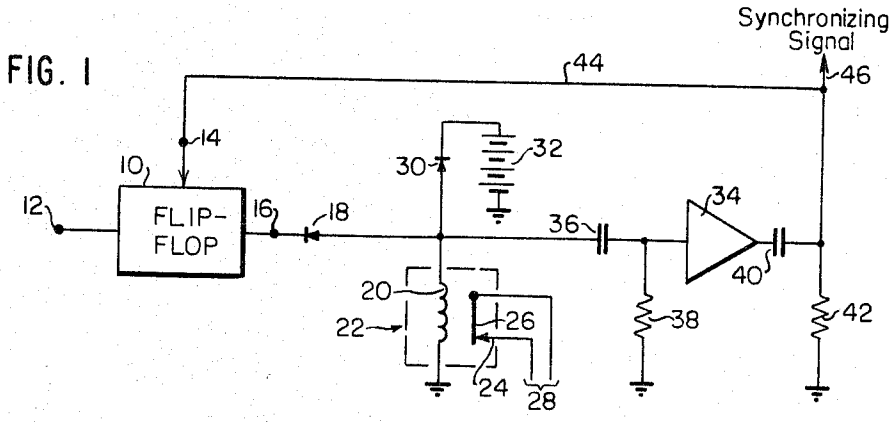
Sept. 27, 1966 N. DE WOLF 3,275,899

RELAY CONTROL CIRCUIT

Filed Sept. 9, 1963

FIG. 1



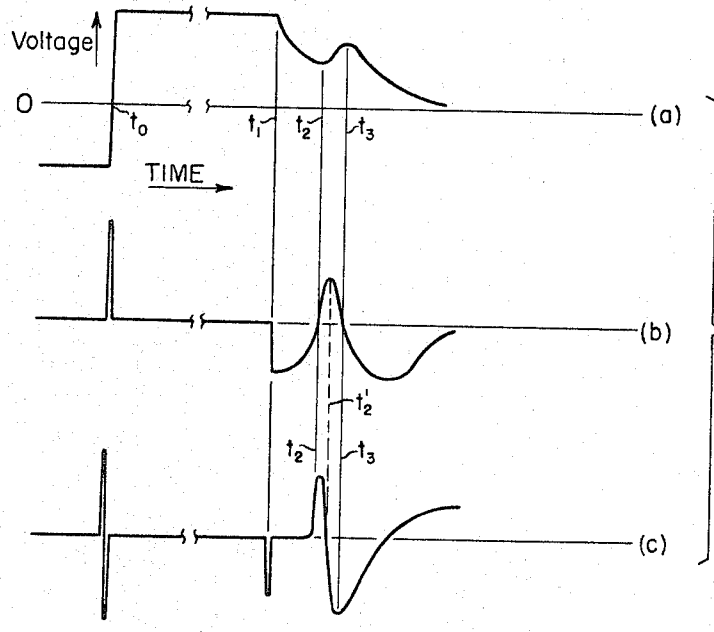


FIG. 2

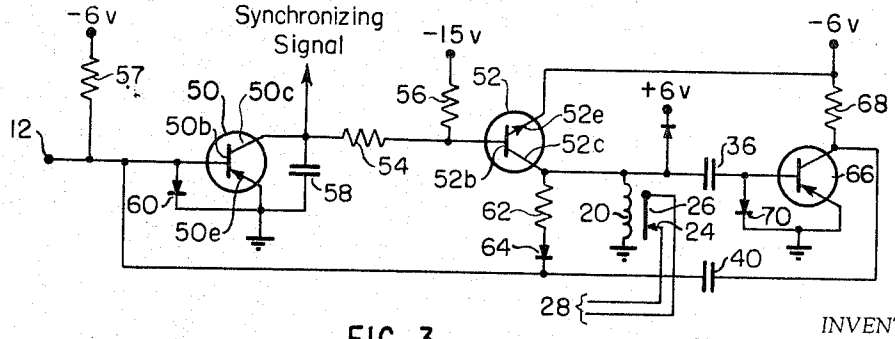


FIG. 3

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RELAY CONTROL CIRCUIT

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My invention relates to an improved electronic circuit for control of a relay. More particularly it relates to a circuit whereby the time a contact, or a set of contacts on a relay first move from the closed (or open) position is accurately and precisely determined without electrical connection to the contacts. Further my invention relates to a circuit for accurately controlling the period that the relay is open or closed.

In many present day applications of relays, choppers, and similar electromechanically operated devices (hereinafter referred to in the specification and in the claims generally as "relays") it is desirable that the time that the contacts first open or close be accurately known so that other circuit functions may be simultaneously initiated. Further, some applications require that the relay be open or closed for only a short period of time, the period being accurately and precisely controlled. For example, if it is desired to "sample" an analog signal, the switch contacts should open or close for a short but precise sampling interval. Alternatively, it may be desired to produce, by relay action a current or voltage pulse train in which the pulses have a precise length. While it is ordinarily possible to determine when the relay contacts have achieved the operated condition by electrical connection to the contacts it has not generally been possible to determine the time when the contacts began to move toward this operated condition i.e. when they first open or close without electrical connection to the contacts themselves. In some relays, such as electromechanical choppers a set of contacts for this purpose cannot be spared for the generation of a synchronizing signal and the so-called chopper "pick" time has been indeterminate. In conventional circuits heretofore used for relay control the sampling interval, i.e. the time the relay contacts are in the operated condition would vary both as function of age, temperature and variations in circuit parameters. To obviate these problems, complex external circuitry and frequent adjustment of the associated signal processing equipment was required.

I have found that the time of operation and the operated period of an electromechanical switch such as a relay, chopper or the like can be accurately and precisely controlled by applying a control signal to the relay coil to cause it to operate, sensing the back voltage generated in the relay coil resulting from movement of the armature when the contact or contacts start to move, and utilizing this back voltage to generate a synchronizing signal which may then be used to cause the relay to return to its rest position, all as will be more fully explained below.

Using the circuit of my invention to be described below, I can accurately and precisely determine the time of relay operation and control the operate period of the relay in a simple manner which is substantially insensitive to variations in circuit parameters, temperature, aging or the like.

Accordingly, a principal object of my invention is to provide an improved relay control circuit.

Another object of my invention is to provide a relay control circuit in which the time that the relay contacts operate is precisely and accurately determined without electrical connection to the contacts and in which the operation interval is accurately controlled.

A further object of my invention is to provide a circuit of the type described which is substantially unaffected by variations in circuit parameters, aging, temperature and the like.

A still further object of my invention is to provide a novel monostable multivibrator circuit particularly useful in the circuit of my invention.

A still further object of my invention is to provide a relay control circuit which is simple and economical of construction but which performs with precision and reliability under unfavorable and varying ambient conditions.

Other objects of the invention will in part be obvious and will in part be apparent hereinafter.

The invention accordingly comprises the features of construction, combination of elements, and arrangement of parts which will be exemplified in the construction hereinafter set forth, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawings in which:

FIG. 1 is a generalized block and line diagram for a circuit embodying the principles of my invention;

FIG. 2(*a*), (*b*) and (*c*) represent waveforms at various points in the diagram of FIG. 1, and are helpful in explaining the operation of the circuit of FIG. 1; and

FIG. 3 is a more detailed circuit diagram of an embodiment of my invention using a reed relay in which the inductance of the relay forms a part of the flip-flop.

Referring first to FIG. 1, I provide a so-called "single shot" flip-flop **10** which may be of conventional construction. The flip-flop includes an input terminal **12** to which a train of control pulses may be applied to operate the flip-flop and cause it to change state. In normal operation the flip-flop when activated by a control pulse, changes state from a first to a second condition, remains in that second condition for a time determined by its internal parameters and then reverts to its initial state. The flip-flop **10** is also provided with a control terminal **14**. If the terminal **14** is supplied with a suitable pulse and the flip-flop is in the second state, it will cause the flip-flop to return to its initial state.

As shown on output terminal **16** of the flip-flop **10** is connected via a diode **18** to the upper end of the coil **20** of the relay generally indicated at **22**. The relay as shown is provided with a single set of contacts, including a fixed contact **24** and movable contact **26**. These contacts are connected to an appropriate point in the using circuit via the leads **28**. While the circuit of my invention is in no way limited to use with relays having only one or two sets of contacts, it is particularly useful with such relays since these relays, in general, do not have available spare sets of contacts which could be used to generate a synchronizing signal.

A diode **30** is connected to one end of the coil **20** as shown and to a source of positive potential, illustratively shown as a battery **32**. The other terminal of the battery is grounded as is the other end of the coil.

The upper end of the relay coil **20** is also connected to an amplifier **34** through a differentiating circuit which includes capacitor **36** and resistor **38**. Similarly the output signal from the amplifier is supplied to a differentiating circuit which includes capacitor **40** and resistor **42**. In the embodiment illustrated in FIG. 1 the output of this second differentiating circuit is connected, via lead **44** to the control terminal of flip-flop **10**. Alternately, or in addition it may also be applied as a synchronizing signal on lead **46** to other parts of the circuit to synchronize other operations of the circuit with the time when the relay contacts open.

For purposes of explaining the operation of the circuit

of FIG. 1, it will be assumed that in its normal state the terminal **16** of the flip-flop is negative with respect to ground so that the diode **18** is conducting. As will be apparent from the following description, this assumption is necessary only for ease of explanation since if the polarities of voltages and diodes were reversed the circuit would be equally useful and workable.

When terminal **16** is negative, diode **18** conducts the current being drawn through the coil **20** of the relay **22**. This current causes the relay to operate and the contacts to close as illustrated in FIG. 1.

When a control pulse of appropriate polarity is supplied to the terminal **12** of the flip-flop, it changes state so that terminal **16** becomes more positive and diode **18** becomes non-conducting. The voltage at the upper end of the coil **20** rises sharply until it is clamped by the diode **30** and battery **32**. The voltage remains clamped at this value until a time which is determined by the decay of the current in the coil **20**. In the absence of the clamping diode **30** and the battery **32**, the voltage at the upper end of the coil would rise to a very high positive value and then decay exponentially. The clamping circuit, limits the value to which the voltage can rise, and the voltage across the coil **20** does not drop below the clamped value of battery **32** until the rate of change of flux has decreased to the value where the induced back voltage in the coil is lower than the battery voltage. Thus, there is a significant period between the time when current is removed from the coil **20** and the time the contacts open.

The voltage waveform at the upper end of the coil **20** is shown in FIG. 2(*a*). As there indicated when the flip-flop **10** is operated, time t_0, the voltage rises sharply to the clamped value, and remains there for a period of time. During all this period the relay normally remains operated.

At time t_1 in FIG. 2(*a*) the voltage at the upper end of the coil begins to drop below the clamped value, and at time t_2, it has dropped sufficiently so that the magnetic force provided by the coil can no longer hold the contacts closed against the spring force tending to separate the contacts. As a result, the movable contact **26** begins to separate from the fixed contact **24**. As soon as it does so however, it generates a back voltage which appears as a small pulse superimposed on the normal exponential decay, as shown in FIG. 2(*a*). This pulse has a maximum value which occurs at time t_3.

The waveform appearing at the upper end of coil **20** is differentiated by the combination of capacitor **36** and resistor **38** and applied as an input signal to amplifier **34**. This differentiated waveform is illustrated in FIG. 2(*b*). It will be observed that the waveform in FIG. 2(*b*) has a positive peak at the time t_2' between t_2 and t_3. After amplification, the output of amplifier **34** is differentiated a second time by the differentiator including capacitor **40** and resistor **42**. The output of the second differentiator is shown in FIG. 2(*c*). It will be observed that the effect of the double differentiation is to provide a relatively sharp positive pulse which occurs almost simultaneously with time t_2 when the contacts first began to open. This pulse may be used as a signal to synchronize other circuit operations with the opening of the relay.

To provide a fixed sampling period, I have found it desirable to connect the output of the second differentiator circuit to the control terminal of the flip-flop. The pulse occurring at the time the relay contacts begin to move resets the flip-flop to cause the relay to return to the operated condition. Under these circumstances the relay contacts are open only a relatively short time and are immediately closed again. However, what is more significant is that the period when the contacts are open is precisely controlled and is substantially independent of circuit aging or variations in the ambient conditions of the circuit.

In FIG. 3 I have illustrated a specific circuit embodying my invention for use in sampling an analog signal for comparison purposes. In this circuit the relay **22** is a reed relay having a coil **20** and contacts **22** and **24**. It is desired that the relay contacts open to sample the signal and close again in a precise time. Further, certain actions in the circuit are to by synchronized with the opening of the contacts.

The specific circuit of FIG. 3 includes a "monostable" or "single shot" flip-flop which includes the two transistors **50** and **52**, transistor **50** being a PNP type and transistor **52** being of the NPN type. The flip-flop is unusual in that both transistors are "on" or "off" at the same time as will be explained in greater detail below.

The flip-flop includes a resistor **54** connected between the collector **50***c* of transistor **50** and the base **52***b* of transistor **52**. The base **52***b* is also connected to a source of bias potential of —15 volts through a resistor **56**. A capacitor **58** is connected between the collector of transistor **50** and ground, the emitter **50***e* of transistor **50** being also grounded. The input terminal **12** of the flip-flop is connected to the base **50***b* of transistor **50**; the base **50***b* is also connected to a negative six volt supply through resistor **57**. As will become apparent from the description which follows, no separate control terminal corresponding to terminal **14** in FIG. 1 is necessary in the flip-flop of FIG. 3, since both input and control signals may be applied directly to terminal **12**. A diode **60** is connected between the base of transistor **50** and ground, and is so polarized that it prevents the base **50** from rising substantially above ground potential. A resistor **62** and diode **64** are connected between the collector **52***c* of transistor **52** and the control terminal **12** for purposes to be explained below. The emitter **52***e* of transistor **52** is connected directly to a negative 6 volt supply. The coil **20** of the relay also forms a part of the flip-flop circuit in FIG. 3; because of this fact, there is no necessity for the diode **18** of the general circuit shown in FIG. 1 in FIG. 3 and it is therefore omitted.

The flip-flop of FIG. 3 operates in the following manner. As shown, the base **50***b* of transistor **50** is returned to a negative potential through resistor **57** and thus the transistor is forward biased. Accordingly, the transistor conducts, its collector current passing through resistors **54** and **56**. The relatively heavy collector current of transistor **50**, passing through resistor **56**, reduces the negative bias on the base **52***b* of transistor **52** sufficiently so that transistor **52** is also forward biased and it conducts. The collector current of transistor **52** when it is conducting passes through the coil **20** of the relay and holds the relay operated.

If, with the circuit in the condition described, a positive pulse is supplied to terminal **12**, it will cause transistor **50** to cease conduction momentarily. As soon as conduction in transistor **50** ceases, transistor **52** is reverse biased because no emitter current is "pulling down" the negative 15 volts which is applied to one end of resistor **56**, and it too ceases conduction. Because of the "inductive kick" provided by the coil **20** when transistor **52** ceases conduction, the potential at the collector of transistor **52** rises sharply to the clamped value of +6 volts, as explained in connection with FIG. 1. This rise in positive voltage is coupled back to the base of transistor **50** via resistor **62** and diode **64** to hold the transistor **50** in a reverse biased condition.

The flip-flop would continue in this condition until the positive voltage at the collector of transistor **52** decayed to a sufficiently low value so that transistor **50** again became conducting, if no other circuit action took place. However, before this occurs, as shown in FIG. 2, the voltage at the collector **52***c* drops sufficiently so that the relay contacts begin to open thus generating the small pulse shown in FIG. 2(*a*).

This waveform is differentiated by capacitor **36**, the associated resistance being the input impedance of the amplifier which includes transistor **66**. In addition to transistor **66**, the amplifier includes a collector resistor

68 which is connected to the negative six volt supply. The transistor 66 is protected against excessive reverse bias by the diode 70. It will be observed that the amplifier which includes transistor 66 inverts the input signal applied to its base. Thus, the waveform of FIG. 2*b* appears (at a different direct voltage level) at the collector in inverted form. This inverted signal is differentiated by capacitor 40 and the effective resistance between terminal 12 and ground to provide a sharp negative pulse. This negative pulse is also applied directly to the base of transistors 50 momentarily forward biasing it and causing it to begin conduction as soon as the contact 26 begins to move. As has been explained, as soon as transistor 50 begins conduction transistor 52 also begins conduction and the relay is returned to the operate condition, the circuit then being in condition to accept the next control pulse applied to terminal 12. The circuit synchronizing signal may be conveniently taken from the collector of transistor 50, as shown in FIG. 3.

Thus, I have provided both in a general and in a specific form an improved relay control circuit which provides a signal exactly synchronized with the initial movement of the relay contacts without electrical connection to the contacts. Further, I have illustrated how, using the circuit of my invention, the time when the relay is open may be accurately and precisely controlled. For example, in practice, using the circuit of FIG. 3, I have found that a synchronizing signal corresponding to the time of opening of the contacts of a reed relay may be generated within 50 microseconds of the time of relay contact opening. Thus the circuit of my invention provides a synchronizing signal which is substantially coincident with the beginning of the operate period so that other parts of the circuit may be exactly synchronized with the relay operation. Finally, I have found that the control circuitry disclosed does not result in extraneous pick up or noise on the contacts themselves, and that that relay contacts may be used, in the circuit of my invention, to switch or control low level signals.

It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above constructions without departing from the scope of the invention, it is intended that all matter containined in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

Having described my invention, what I claim as new and desire to secure by Letters Patent is:

1. A circuit for providing a pulse of electrical energy which is substantially coincident with the first movement of the armature of a relay comprising, in combination, a relay, said relay having an inductive coil and an armature, means for applying a control signal to said relay coil to cause said relay to change state, means responsive to the induced voltage pulse appearing across said relay coil when the armature of said relay begins to move for generating said pulse, said last mentioned means including in series relationship, a first differentiating circuit, a amplifier and a second differentiating circuit.

2. The combination defined in claim 1 in which said means for applying said control signal includes a flip-flop, said flip-flop causing current to flow through said coil in a first direction when said flip-flop is in a first state and causing said current to abruptly cease when said flip-flop is in a second state, the potential across said relay thereby rising sharply and diminishing gradually to form said control signal.

3. A circuit for controlling the operate period of a relay comprising, in combination, an electrical device responsive to a control signal capable of having a first and a second state, a relay having an inductive coil and a movable armature, means interconnecting said relay coil and said electrical device whereby said relay is in a first state when said device is in a first state, and transfers to a second state some time after said electrical device transfers to said second state, means for detecting the induced voltage pulse appearing across said relay coil when said armature begins to move as said relay transfers from said first to said second state to thereby form a pulse which is substantially coincident with said armature movement, and means supplying said pulse to said two state device to cause said device to assume said first state.

4. The combination defined in claim 3 in which said detecting means includes means for doubly differentiating said pulse and means for amplifying said pulse.

5. The combination defined in claim 3 in which said two-state electrical device is a monostable flip-flop.

6. The combination defined in claim 3 in which said two-state electrical device is a monostable flip-flop, said flip-flop causing current to flow through said coil in a first direction when said flip-flop is in a first state and causing said current to abruptly cease when said flip-flop is in a second state.

7. A monostable flip-flop circuit comprising, in combination, a first transistor, a second transistor of a type complementary to said first transistor, means biasing said first transistor for conduction, a voltage source, a resistor in series with said voltage source, means connecting an element of said first transistor other than the base thereof to the end of said resistor not connected to said voltage source, said voltage source being of a polarity to reverse bias said second transistor, means connecting the base of said second transistor to the end of said resistor not connected to said voltage source, conduction of said first transistor reducing the reverse bias on said second transistor so that said second transistor is conductive, an inductor connected to an element other than the base of said second transistor, whereby when said second transistor ceases conduction an induced back voltage of a polarity to maintain such first transistor in a non-conductive state appears at the junction of said inductor and said transistor element, means interconnecting the junction of said second transistor element and said inductor and the base of said first transistor, to thereby cause said first transistor to become non-conducting for a predetermined period.

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